Effect of soil moisture gradient on structure of broad-leaved /Korean pine forest in Changbai Mountain

WANG Yan[1,2], WANG Qing-li[1], DAI Li-min[1**], WANG Miao[1], ZHOU Li[1], DAI Bao-qing[1]

[1] *Institute of Applied Ecology, Chinese Academy of Science, Shenyang 110015, P. R. China*

[2] *Chemical and Life Science Institute of Shenyang Normal University, Shenyang 110034, P. R. China*

Abstract: A 112 m × 8 m sample plot which includes 14 sub-plots was set up along the slope in Hongshi Forestry Farm of Baihe Forestry Bureau (127°55'E, 42°30' N), Jilin Province in August 2002. Community structure, soil moisture contents at 0-10 cm and 10-20 cm in depth, water content of litter as well as the contents of C, N and P of litter, living leaves and branches in the broad-leaved/Korean pine (*Pinus korraiensis*) forest were measured in each sub-plot on different slope positions. The analytical results showed that there existed an obvious soil moisture gradient along the slope: upper slope < middle slope < lower slope. The difference in soil moisture contents on different positions of slope led to a change of the stand structure of the broad-leaved/Korean pine forest. The proportion of *Quercus mongolica* gradually increased with the decrease of soil moisture content and that of other major tree species in the broad-leaved /Korean pine forest gradually decreased or disappeared. The dynamic of soil moisture contents in the litter layer was as same as that in mineral soils. The decomposition rates of the litter on different slope positions were different and the dry weights of existent litter varied significantly. The soil nutrients in the litter on the lower slope was richer than that on the upper slope due to the different stand structure on the different slope positions. The moisture content and nutrient contents of soil had effects on the composition, decomposition, and the nutrient release of litter, thus affecting stands growth and stand structure and finally leading to the change of ecosystem.

Key words: Soil moisture gradient; nutrient; Stand structure; Broad-leaved/Korean pine forest

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Introduction

The tendency of global warming has been recognized in the whole world. Generally, people think the precipitation will become less and unstable due to the climate warming (Yan 1999). China locates on the decreasing section of precipitation of middle latitudes where the climate presents a warm and dry tendency (Shi 1996). Even if precipitation may increase at some places, the aridity tendency is still obvious because of the increasing of evaporation along with the temperature rising. This has a far-reaching influence to the regional environment.

Terrestrial transect research is a very important method to acquire global change information both in small scale and global level. NECT (Northeast China Transect) is a well known terrestrial transect beginning at the Changbai Mountain from the east extending to the west along a precipitation gradient (Zhang *et al.* 1998). The ecosystems vary from a typical forest to typical grassland from the east to the west. The influence of aridity on the ecosystems is obvious and complicated, including the changes of the ecosystem structure, productivity, bio-chemical circulation, etc.. The broad-leaved/Korean pine (*Pinus korraiensis*) forest is the climactic community of Changbai Mountain area. Changbai Mountain area is located at the starting point of the NECT. Thus, exploring the influences of soil moisture condition and aridity on the broad-leaved /Korean pine forest is a very important part of the transect study. Many researches have been done in the broad-leaved/Korean pine forest (Hao *et al.* 1994; Yan and Zhao 1995; Xu *et al.* 1985). Some simulating experiments for dominant trees, such as *Quercus mongolica*, *Pinus koraiensis*, *Juglans mandshurica*, *Fraxinus mandshurica* in the broad-leaved/Korean pine forest, have been carried out under controlled water gradient conditions. However, studies on the broad-leaved/Korean pine forest in natural water gradient status have not been paid enough attention yet.

In fact, there is no obvious precipitation gradient within the broad-leaved/Korean pine forest in Changbai Mountain. But landform could have an influence on the spatial allocation of soil water to form a soil water gradient or heterogeneity in the ecosystem along a slope (Qiu 2001). In Changbai Mountain, the soil water gradient on a slope could be also identified, especially on a deep slope, where the original community adapts to such a water gradient condition for a long time without human disturbance. In this

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Biography: WANG Yan (1970-), female, Ph. D, associate professor. E- mail: wyancn2002@yahoo.com.cn

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**Corresponding author

study, we used the soil water gradient instead of the precipitation gradient to study the effect of aridity on forest ecosystem and hope to give a clue to show and understand the effect of aridity on the broad-leaved/Korean pine forest.

Study site and method

Study site

This study was carried out in Hongshi Forestry Farm of Baihe Forestry Bureau, Jilin Province (127°55'E, 42°30' N). The study area is characterized by typical continental and temperate climate, drought and windy in spring, hot and rainy in summer, and dry and cold in winter. Annual mean temperature ranges from −7.3 to 4.9°C. Annual precipitation is in range of 600-900 mm, mainly concentrated in the time period from June to August. The frost-free period is about 109-141 d (Shi 1996).

The study site was chosen on south and 30-degree slope extending from 660 m to 730 m above sea level. The natural broad-leaved/Korean pine forest in the site has never been disturbed and the ecosystem was stable and adaptive to the environment for a long time.

Method

The study was carried out in August 2002. A belt of sample plot, 112 m long and 8 m wide, was set up along the slope. The plot was divided into 14 continuous sub-plots, 8 m×8 m for each in size. In each sub-plot, the community structure was investigated, the soils of 0-10 cm and 10-20 cm in depth were separately sampled for measuring the soil water content, and the litter was also sampled in area of 0.5 m×0.5 m for measuring the water content, fresh weight, dry weight, and the contents of C, N and P. At the same time, the living leaves and branches of major trees on the upper slope and lower slope also were separately collected for measuring the contents of C, N and P.

The sub-plots were grouped into upper-slope group (No.1-4), middle-slope group (No.5-10), and lower-slope group (No.11-14).

The samples of litter, leaves and branches were dried at a temperature of 105 °C for half an hour and then dried at 80°C until a stable weight. C content was measured by the heated K_2CrO_7 method. Total N content was measured by the Kjeldahl analyzer and P content was measured by Mo-Sb colorimetry method. Water contents of soil and litter were measured by heating and drying method under 105℃.

Results

Soil moisture gradient along the slope

The soil moisture is a key ecological factor influencing the community. The reallocation of soil water on the slope could make a soil moisture gradient along the slope. The investigation results showed that the soil water contents had an increasing tendency from sub plot No.1 to No.14 along the slope both in the 2 soil layers, although there was some fluctuation (Fig. 1). The soil water content at 0-10 cm layer was higher than that at 10-20 cm layer due to a high raining frequency in August in Changbai Mountain, and another important reason was that the litter and humus on the soil surface could reserve water, but roots of plants absorbed water in the deeper soil layer (Xu 2001).

The soil moisture gradient showed an obviously decreasing trend on different slope positions from the lower to the upper slope in the 2 soil layers (Fig. 2). Thus the study on the adaptation and changes of the broad-leaved /Korean pine forest under the obvious water gradient is very meaningful.

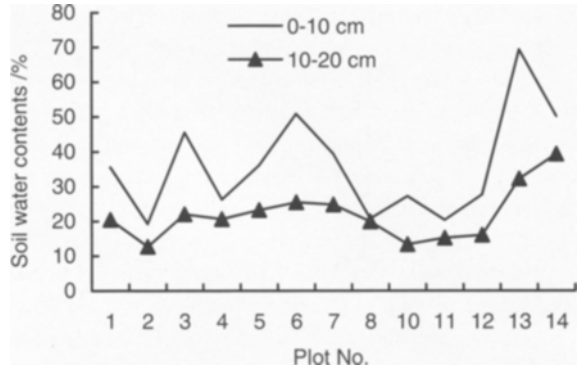

Fig.1 Soil water contents of all sup-plots along the slope
(No.1-4: upper slope, No.5-10: middle-slope, No.11-14: lower-slope)

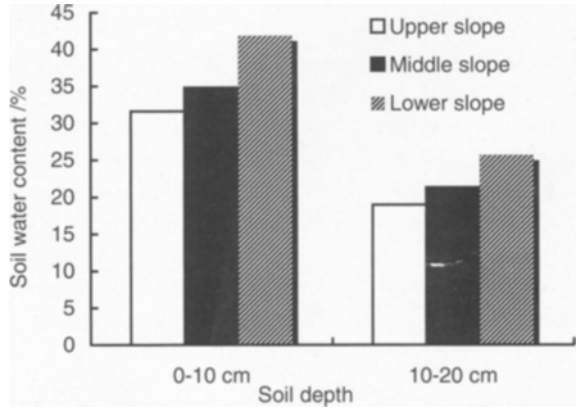

Fig.2 Comparison of soil water contents at different soil layers on different slope positions

Relationships between the litter characteristics and the soil moisture gradient

Litter has a significant function in reserving water, forming soil structure, and maintaining soil nutrient in the ecosystem. The status of litter could reflect the change of the stand structure and the environmental factors.

Weight of existing litter

Decomposition of litter is a very important process to the nutrient cycling of forest ecosystem. Suitable water

condition could accelerate the decomposition of litter, and aridity could defer the decomposition of litter.

The decomposition of litter on the upper slope was the slowest. As a result, the dry weights of existing litters on different slope positions were significantly different (F=5.7075>$F_{crit\ 0.05\ 2,\ 11}$ =3.9823) (Fig. 3).

The difference of litter decomposing process could influence the nutrient status and soil structure on different slope positions. Existent litter weight, in another word, the decomposition rate of litter was affected directly by temperature, litter nutrient status, and the water status.

Fig. 3 Biomasses of litters on different slope positions

Water content of litter

Water content of litter is consistent with the water content of air and soil interface (Yan *et al.* 2001). It was clear from this study that soil water content directly influenced the water status of litter. Thus water content of the litter was related to the water redistribution by the slope, decreasing from the lower slope to the upper slope (Fig. 4). This change tendency was the same as the change in the soil. The result also showed that the dry weight of litter had a negative correlation to the water content of litter (r=-0.30).

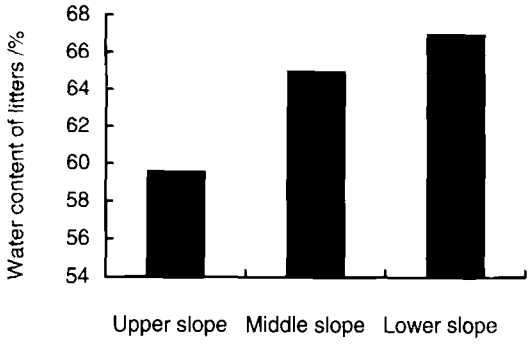

Fig. 4 Water contents of litters at different slope positions

Nutrient content of litter

The litter is a nutrient pool in the forest ecosystem. Its decomposition is very important to maintaining the soil fertility. Many factors could influence the nutrient release of litter in an ecosystem, especially the C/N ratio and water content. Generally, the litter with a C/N ratio under 25 is easy to decompose. The higher the C/N ratio, the more difficult the decomposition of litters is. P is another important nutrient element in the ecosystem. Cromack and Monk (1975) reported that C/P ratio of 240 was a critical value for the fixing of P during the decomposition process of litter. Our study showed that C/N and C/N/P ratios of litter increased from the lower slope to the upper slope in study site. This indicated that the nutrient condition became worse from the lower to the upper slopes. All ratios of C/P were higher than 240 (Table 1), which indicated the status of P shortage. Generally, the nutrient status of soil on the lower slope was better than that on the upper slope, which has an influence on the nutrient content of trees. However water content of soil could be another factor affecting the nutrient absorption of trees. Water wane in soil leads to the absence of nutrient to the plants, and plant growth is limited under controlled experiment (Wang *et al.* 2001; Wang *et al.* 2002). The dry weight of litter and the C/N ratio showed a negative relationship (Fig. 5).

Table 1. Nutrient contents in litters at different slope position / g·kg^{-1}

Slope position	C	N	P	C/N	C/N/P
Upper slope	434.878	10.043	0.700	43.3	621/14/1
Middle slope	407.757	10.139	0.660	40.2	618/15/1
Lower slope	366.607	11.797	0.840	31.1	436/14/1

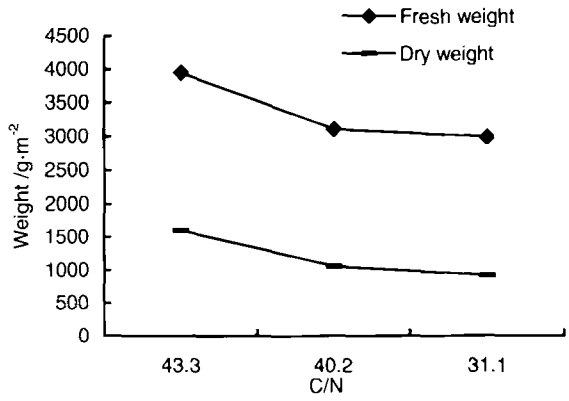

Fig. 5 Relationship between C/N ratio and existed litter weights

Nutrient contents of major trees

The nutrient status of trees could influence the decomposition of litter directly. The nutrient contents in living parts of major trees were shown in Table 2. For each species the C/N ratio of branches were about 2-4 times higher than that of leaves. This was smiliar to the result of Gao (2000) for *Pinus massonian*.

The C/N ratio (>25) of *Pinus koraiensis* leaves indicated why the fallen pine needles were difficult to be decomposed.

Moreover the leaves of *Quercus mongolica* were more difficult to be decomposed due to the thick dipcoat and cutin layer on the leaf surface.

For the same tree species on the upper and lower slopes, the ratios of C/N and C/N/P of leaves and branches were different (Table 2). *Quercus mongolica* had the highest P content on the lower slope, and the lowest P content on the upper slope. All the P contents of leaf samples of *Pinus koraiensis* and *Quercus mongolica* on the lower slope were higher than those on the upper slope.

Table 2. Nutrient contents in leaves and branches of some major trees (unit: g·kg^{-1})

Position	Species	Plant organ	C	N	P	C/N	C/N/P
Lower slope	*Fraxinus mandshurica*	leaves	416.223	21.362	1.310	19.5	318/16/1
		branches	455.37	5.866	0.600	77.6	759/10/1
	Tilia amurensis	leaves	480.637	21.123	1.630	22.7	295/13/1
		branches	432.117	10.641	1.290	40.6	335/4/1
	Quercus mongolica	leaves	437.447	25.029	1.850	17.5	236/14/1
		branches	442.494	6.472	0.930	68.4	476/7/1
	Pinus koraiensis	leaves	490.258	15.065	1.480	32.5	331/10/1
		branches	550.146	8.162	1.210	67.4	455/7/1
Upper slope	*Quercus mongolica*	leaves	450.692	19.449	1.250	23.2	361/16/1
		branches	457.974	6.121	0.670	74.8	683/9/1
	Pinus koraiensis	leaves	492.749	12.611	1.250	39.1	394/10/1
		branches	519.585	6.297	0.730	82.5	712/9/1

Relationships between the community structure and the soil moisture gradient

People often thought that the broad-leaved/Korean pine forest will be replaced by *Quercus mongolica* forest if the precipitation decreases to a certain degree, because *Quercus mongolica* is stronger in drought resistance than Korean pine. Therefore, the dominancy of these two tree species should be the key evidence in indicating the succession status under the soil water stress. Korean pine could grow on the entire slope, but mainly centered on the upper and middle slopes, and a little on the lower slope due to a high content of soil water (Fig. 6). Xu (2001) thought that air moisture was more important than soil water content for the growth of Korean pine. In Changbai Mountain, the air is humid, thus the soil water content has no significant effect on the growth of Korean pine.

The percentage of *Quercus mongolica* in broad-leaved/Korean pine forest increased significantly under the soil water stress (Fig.7). Both Korean pine and *Quercus mongolica* are some kind of drought resistant species. However, if the air humidity decreases to a certanin degree, *Quercus mongolica* should be more adaptive than Korean pine in the community. If the aridity becomes more serious, the broad-leaved/Korean Pine forest might success to *Quercus mongolica* forest.

Distribution of other major tree species in the broad-leaved/Korean pine forest also changed along the slope. For example, *Acer pseudo-sieboldianum* had a high proportion on the middle and upper slopes, *Tilia amurensis* mainly grew on the lower slope, *Fraxinus mandshurica* existed sparsely on the foot of the slope, and both *Tilia amurensis* and *Fraxinus mandshurica* disappeared on the upper slope.

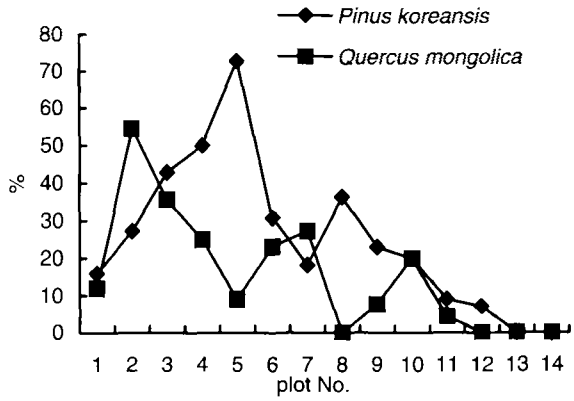

Fig. 6 The changes in percentages of *Quercus mongolica* and *Pinus koraiensis* along the soil moisture gradient
(No.1-4: upper-slope, No.5-10: middle-slope, No.11-14: lower-slope).

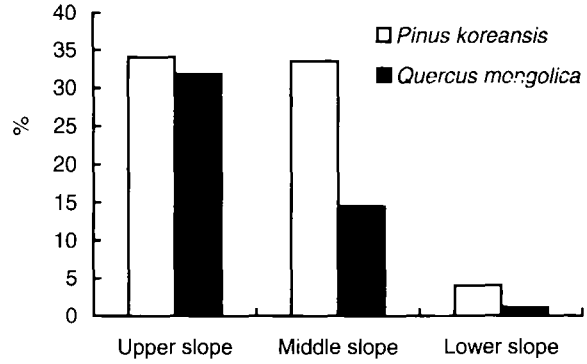

Fig. 7 The percentages of *Pinus koraiensis* and *Quercus mongolica* species in broad-leaved/Korean pine forest along the slope

Conclusion and discussion

The community structure, decomposition rate of litters, and the nutrient status of trees were all influenced by the soil moisture gradient. Soil moisture gradient along a slope could be used as an indication of the influence of aridity on the change of the forest ecosystems.

In general, the ecological process of a community is mainly influenced by water, sunlight, and temperature. However, in a small scaled area as in this study, the sunlight and temperature has no significant differences. Therefore, the soil water condition along the slope must be the crucial factor affecting the dynamics of the ecosystems. In this study, we found that Korean pine and *Quercus mongolica* could grow on the upper slope because they were relatively drought tolerence when soil water content decreased. Other trees, such as *Fraxinus mandshurica* and *Tilia amurensis,* which are usually important in broad-leaved Korean pine forest, could not grow on the upper slope because of the water stress.

The broad-leaved/Korean pine forest is gradually replaced by *Quercus mongolica* forest as the precipitation decresed from east to west along the NECT because *Quercus mongolica* is more drought tolerent than *Pinus koreaensis* which needs a certain air humidity (60%-72%) (Xu 2001). Will the broad leaved/Korean Pine forest be replaced by *Quercus mongolica* forest in Changbai Mountain? It depends on the degree of aridity. From this study, we could conclude that there was a tendency that the community structure was changing and *Quercus mongolica*'s propotion was increasing under a soil water gradient.

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